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EXTERNAL DOSE ESTIMATES FOR FUTURE BIKINI ATOLL INHABITANTS

P. H. Gudiksen, T. R. Crites, and W. L. Robison

March 3, 1976

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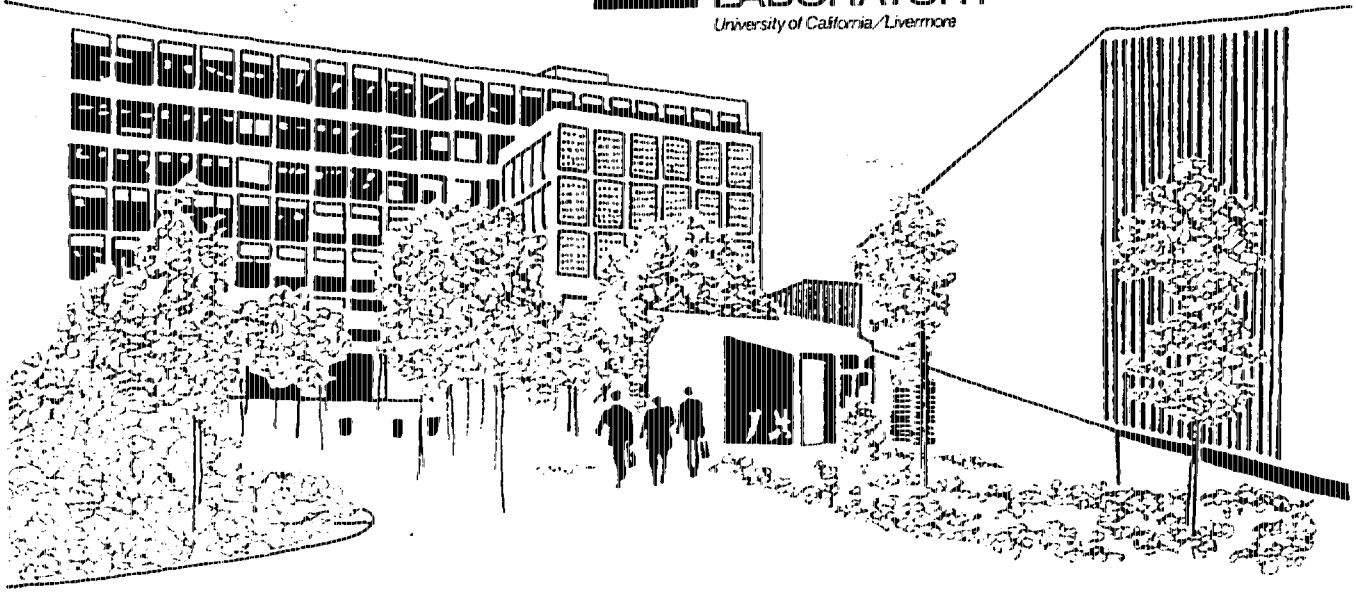

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EXTERNAL DOSE ESTIMATES FOR FUTURE BIKINI ATOLL INHABITANTS

Abstract

To evaluate the potential radiation doses that may be received by the returning Bikinians, we surveyed the residual radioactivity on Bikini and Eneu Islands in June of 1975. An integral part of the survey included measurements of gamma-ray exposure rates which are used to estimate external gamma-ray doses. The survey showed that on Bikini Island the rates are highly variable: values near the shores are generally of the order of 10 to 20 μR/h, while those within the interior average about 40 μR/h with a range of roughly 30 to 100 μR/h. Eneu Island, however, is characterized by more or less uniformly distributed gamma radiation levels of less than 10 μR/h over the entire island.

These data, in conjunction with population statistics and expected life styles, allowed us to estimate the potential external gamma-ray doses associated with proposed housing locations along the lagoon road and within the interior portions of Bikini Island as well as along the lagoon side of Eneu Island. As expected, living on Eneu Island results in the lowest doses: 0.12 rem during the first year and 2.9 rem during 30 years. The highest values, 0.28 rem during the first year and 5.9 rem over 30 years, may potentially be received by inhabitants living within the interior of Bikini Island. Other options under consideration produce intermediate values.

Introduction

Bikini Atoll was one of the U.S. nuclear weapons testing sites in the Pacific. It is situated in the northern part of Micronesia in the Central Pacific Ocean about 3600 km southwest of Honolulu. The atoll consists of a number of small islands on an elliptical coral reef surrounding a lagoon with major and minor axes having dimensions of 35 and 27 km, respectively (Fig. 1). The total land area is about 6 km^2, and the land height generally averages 3 to 5 m above mean sea level. The islands vary in size from small sandbars of

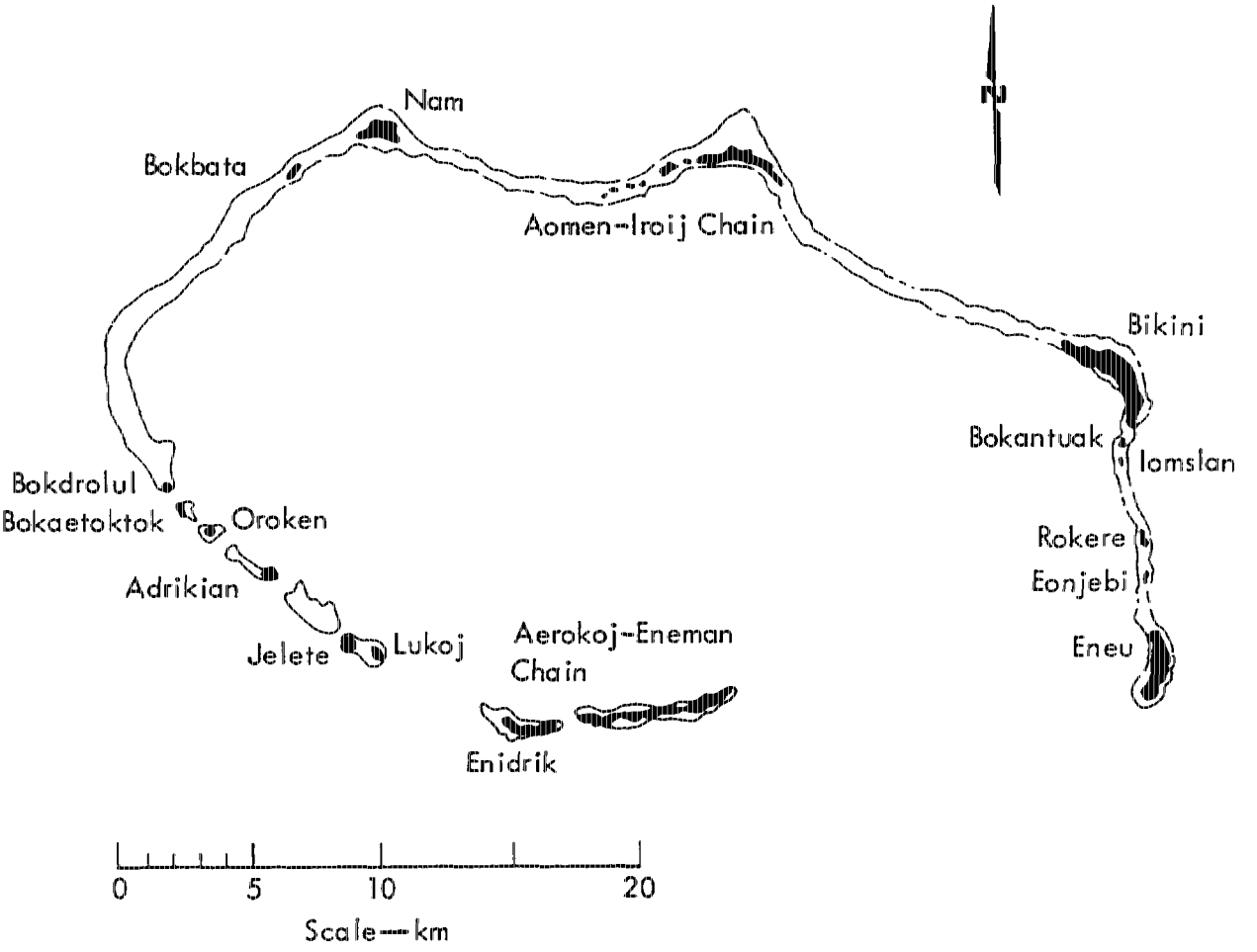

Fig. 1. Map of Bikini Atoll.

a few hundred square meters to islands of about 2 km^2. Bikini and Eneu are the most likely islands to be reinhabited.

A total of 23 nuclear tests took place during the testing period. Most of the tests were conducted on barges anchored in the lagoon or on the reef. All islands were subjected to varying degrees of close-in fallout. Generally, the prevailing winds transported the radioactive debris clouds toward the southwest. One exception, however, occurred during the Bravo event when unexpected changes in the wind directions caused the cloud to travel toward the east over Bikini Island. Most of the radioactive contamination on Bikini Island is due to this event.

This recent survey was designed to evaluate the potential external gamma doses associated with proposed housing locations on Bikini and Eneu Islands, and to evaluate the potential doses received through the major terrestrial food crops on the atoll. In this report we only assess the external gamma doses.

Techniques Used to Measure Gamma-Ray Exposure Rates

Because the external dose is primarily due to gamma-emitting radionuclides, with only minor contributions from alpha and beta emitters, we had to obtain the best possible description of the geographical variability of the gamma-ray exposure rates on Bikini and Eneu Islands. Any technique for measuring gamma exposure rates has its own set of limitations (e.g., nonlinear energy response, portability of equipment, and extent of geographical coverage). We therefore used four different techniques to obtain the detailed geographical coverage and accuracy we desired: portable, hand-held NaI scintillation detectors, a commercially available pressurized ion chamber, and two types of thermoluminescent dosimeters (TLD's).

The portable scintillation detectors consisted of a 2.5-cm-diam x 3.8-cm-long NaI crystal with rate meter readout. The detectors were calibrated in microroentgens per hour (μR/h) against a ^{137}Cs point source on the primary calibration range of the National Environmental Research Center, Las Vegas, Nevada. Calibration was repeated on selected instruments following the survey.

The detectors measured the exposure rates at 1 m above the ground at about 2500 locations on a 30-m rectangular grid over the entire surface of Bikini Island, and at about 200 locations on a 120-m grid on Eneu Island. Since the response of the detectors was energy-dependent and they were calibrated with a point source, they were expected to overrespond to the gamma flux on the atoll because the flux is depth distributed and has a higher scatter component — and, therefore, a lower energy — than the point source. The detectors could be carried easily, which allowed us to make measurements at many locations on a uniform grid of the islands. They are virtually insensitive to cosmic radiation.

The response of the detector was compared with that of the pressurized ion chamber over the entire range of observed exposure rates. The ion chamber consists of a stainless steel sphere filled with high-pressure ultra-pure argon. The current produced by the radiation-induced ionization within the chamber is measured by a sensitive electrometer with digital readout. The detector was calibrated by the manufacturer and verified by several ERDA laboratories. It exhibits a relatively flat energy response over the gamma-ray energies of interest in a typical environmental

radiation field. Therefore, its response is often used as a reference to which other measurements may be compared. The chamber walls are sufficiently thick to render the detector insensitive to the beta radiation present in fallout fields. The instrument is, however, sensitive to cosmic radiation.

Further gamma exposure rate comparisons were made by means of LiF and CaF_2: Dy thermoluminescent dosimeters (TLD's) placed at 80 locations. The LiF chip displays an essentially flat energy response and excellent thermal stability. The response of LiF is within approximately 1% of being air equivalent for a typical environmental radiation field. The CaF_2: Dy TLD's have an enhanced energy response at low energies, and were used to detect possible low-energy radiation fields by comparison with the LiF readings. The LiF and CaF_2 chips were matched to 5% and 4% respectively within each batch. The TLD's were annealed on the atoll immediately before being placed on the two islands. Two Lawrence Livermore Laboratory (LLL) plastic personnel badges containing three LiF and three CaF_2 chips were placed at each field location. The TLD packets were attached to trees by nylon straps or placed on wooden stakes at a height of 1 m above the ground. The locations were carefully chosen to obtain exposures over the full range of gamma exposure rates observed by the portable instrument survey. After the 3-month exposure period, the dosimeters were retrieved and handcarried (by air) in a lead container to Livermore for readout.

We studied calibration and signal fading by exposing separate sets of TLD's to a ^{137}Cs point source before and after the exposure period. A special low-scatter calibration fixture was constructed for field use which aided in obtaining uniform, reproducible exposures. The intensity of the ^{137}Cs calibration source was determined by

- Using a NBS calibrated Radocon* chamber
- Comparing the response of a set of TLD's exposed to a NBS-calibrated ^{60}Co source to that obtained from the calibration source

The calibration is known within ± 3% at one standard deviation.

We stored a set of control TLD's in a lead pig on a "clean" island in the Marshalls during the

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*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable.

exposure period for background determination. The background exposure was essentially all contributed by cosmic radiation during the 3-month exposure period and during the aircraft flight to LLL. Additional TLD's were stored on the periphery of the lead pig to identify possible inadvertent exposures. The average background exposure for the two types of TLD's was subtracted from all field measurements so that the results represent only the terrestrial radiation exposure rates. We found that sunlight had a negligible effect on this packaging arrangement.

The correspondence between the results obtained with the NaI scintillator and the pressurized ion chamber is presented in Fig. 2. The ion chamber readings have been reduced by 3.3 μR/h, the cosmic-ray contribution at that latitude. The figure shows that the NaI scintillator overresponded because of its nonlinear energy characteristics. The discontinuity at about 30 μR/h occurs at a range switching point on the scintillator. Three locations were measured on both low and high range, and those results are shown in solid circles. On the scintillation instrument's low range of 0 to 30 μR/h, a correspondence near 1:1 is observed. On the higher range, the correspondence, though

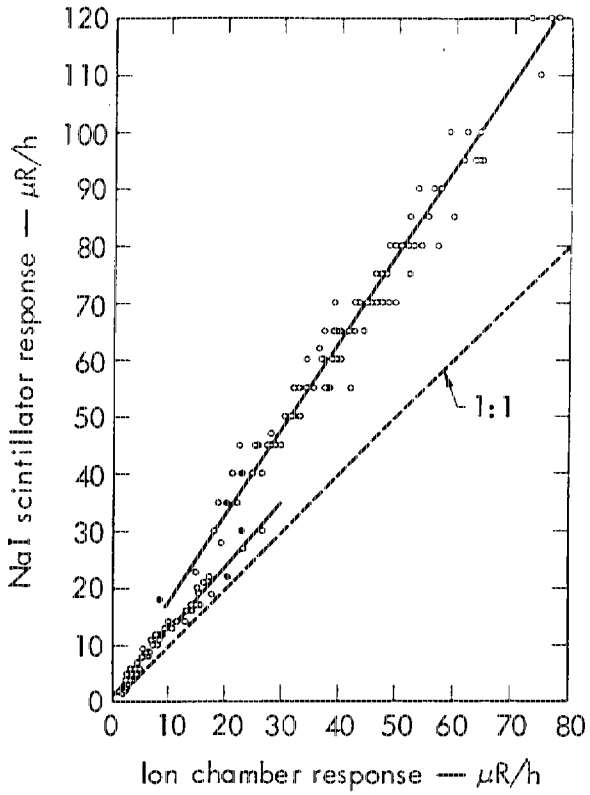

Fig. 2. Comparison of responses of the NaI scintillator and the pressurized ion chamber.

linear, deviates more markedly from the 1:1 relationship.

The TLD results indicated that the CaF_2 TLD's overresponded by approximately 21% relative to the LiF. This is consistent with similar studies made at Enewetak Atoll[1] and with environmental monitoring performed by LLL in the U.S. The overresponse varies with energy and this ratio (1.21) corresponds to an average gamma energy of about 500 keV. This is reasonable based on the CaF_2 enhanced low-energy response and the predominance of ^{137}Cs activities distributed in the soil.

To assess the beta contribution to the LiF exposure rates, various

thicknesses of aluminum absorbers were placed over an array of dosimeters at three sites on Bikini Island. A feather analysis of the beta attenuation curves gave a maximum beta energy between 1.5 and 2.2 MeV. Given the known predominance of ^{90}Sr-^{90}Y beta activities in the soil, this energy range is consistent with the 2.27 MeV ^{90}Y beta radiation. The analysis also revealed that the average beta contribution to the total LiF exposure rates was 27% — a rather significant contribution. Therefore, it was necessary to reduce the LiF results by this amount to obtain the free-air gamma-ray exposure rates.

The comparison between the ion chamber results and the LiF gamma-ray exposure rates is presented in Fig. 3. A linear regression of the two data sets gives agreement of about 13% between the two methods. One also finds that the correlation of points in Fig. 3 is not as good as that in Fig. 2. This difference is most likely due to the beta contribution to the LiF results, which may vary throughout the islands, causing spread in the data. Departure from the 1:1 relationship in Fig. 3 may be due to an over-correction of the TLD data for beta response or to insufficient consideration of the ion chamber data for energy dependence.

Calibration of the pressurized ion chamber against a point ^{226}Ra source, the method used with the instrument in this study, leads to about a 3% overestimate in the measurement of "typical" environmental fields in this country.[2] If a similar correction were made to these data, the agreement of the two independent exposure-rate determinations (ion chamber and LiF TLD) would be within 10%. This is considered to be satisfactory agreement between the two reference techniques used in this work. Hence, on the basis of these results, the NaI scintillation readings were normalized to the output of the pressurized ion chamber.

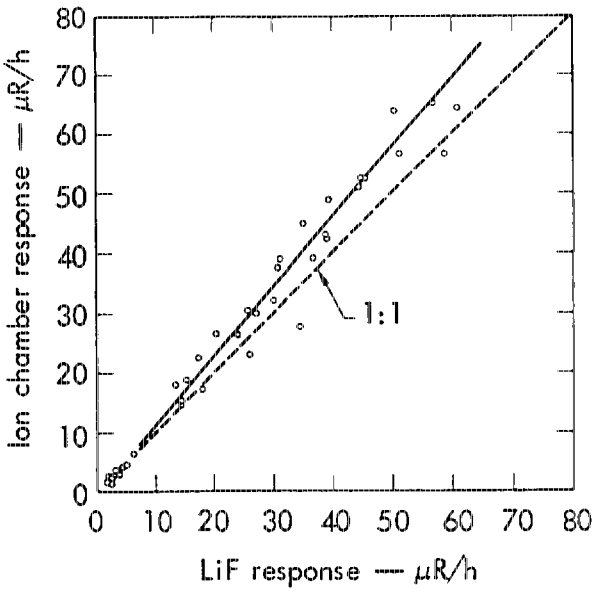

Fig. 3. Comparison of responses of the pressurized ion chamber with LiF TLD's. The contribution due to cosmic radiation has been subtracted.

Results of Gamma-Ray Exposure Rate Measurements

The geographical variability of the gamma-ray exposure rates for Bikini and Eneu Islands is shown in Figs. 4 and 5. The contribution due to cosmic radiation has been subtracted. On Bikini Island the individual measurements from which the contour levels were derived are listed in the Appendix. Note the complex patterns displayed throughout the island. This complexity may be due, in part, to the inhomogeneity in the original fallout pattern produced by the Bravo event, but it certainly reflects the extensive earth moving activities performed over the entire island as part of the agricultural rehabilitation program. The exposure rates near the shores are typically of the order of 10 to 20 μR/h, while the elevated interior values vary over a wide range of roughly 30 to 100 μR/h. The interior portions of the island may be visualized as having a general background of about 30 to 40 μR/h with numerous irregularly shaped areas exhibiting elevated levels superimposed in a random fashion over this general background. This may also be visualized by viewing the three dimensional computer generated graphical displays of the exposure rates (Figs. 6a, b and c). The vertical coordinate is a measure of the gamma exposure rate. Thus, the elevated irregularly shaped areas appear as "peaks" while the lesser values near the shores appear as relatively low flat areas. Note especially the low flat area situated on the ocean side near the center of the island (Fig. 6a).

The gamma exposure rates measured on Eneu Island (Fig. 5) show that the island is characterized by low (less than 10 μR/h) and more or less uniformly distributed gamma radiation levels over the entire island.

These total gamma-ray exposure rates are the basis for the external dose estimation. However, to determine the annual dose and dose commitment, it was also necessary to determine the fractional contribution made by the predominant gamma-emitting radionuclides distributed in the soil. Based on our experience at Enewetak Atoll[1] and the data of Bennett and Beck[3] obtained during the 1967 Bikini Survey, we expected that the primary contribution to the gamma exposure rates would be due to ^{137}Cs and ^{60}Co activities in the soil. Trace quantities of other gamma emitters such as ^{125}Sb,

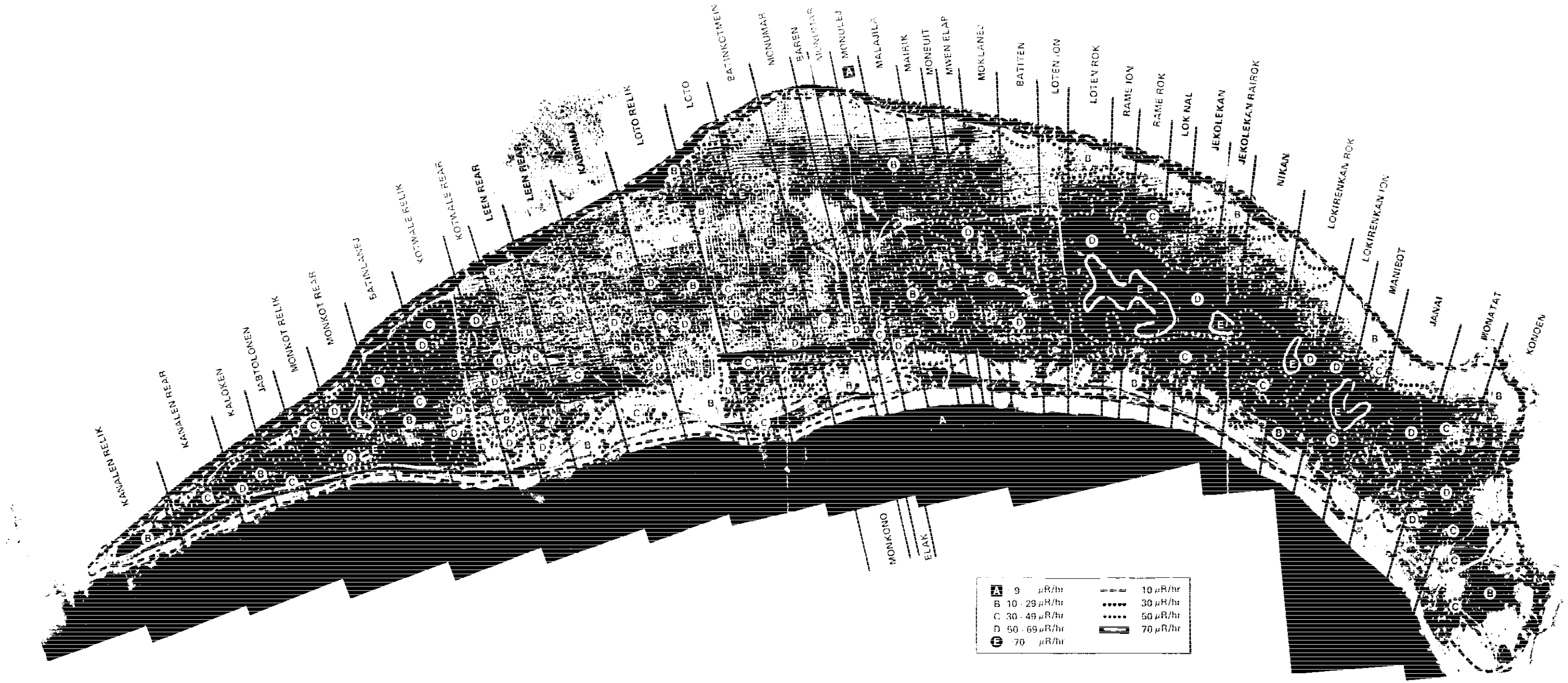

Fig. 4. The geographical variability of the gamma-ray exposure rates (μR/h) measured 1 m above the ground on Bikini Island. The contribution due to cosmic radiation has been substracted. The contours were drawn on the basis of the data shown in the Appendix. The straight lines drawn across the island denote boundaries of land parcels (watos) owned by the families whose names appear in the upper part of the photograph.

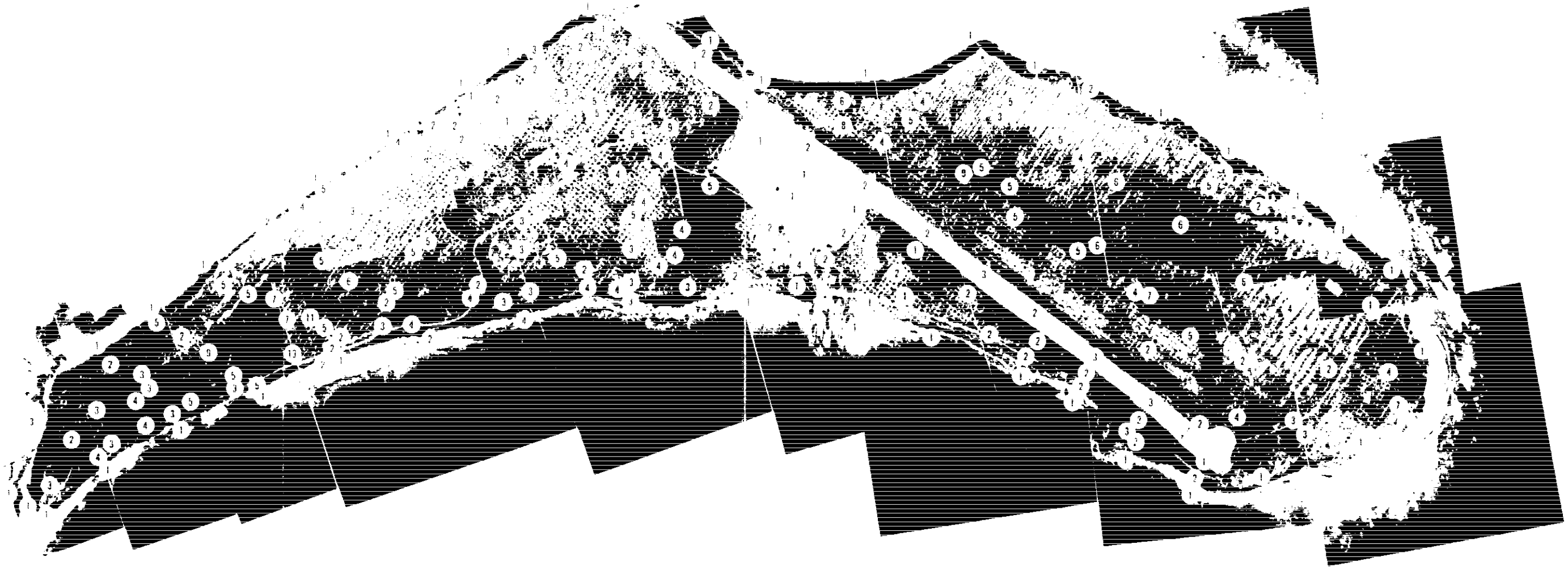

Fig. 5. The geographical variability of the gamma-ray exposure rates (μR/h) measured 1 m above the ground on Eneu Island. The contribution due to cosmic radiation has been subtracted.

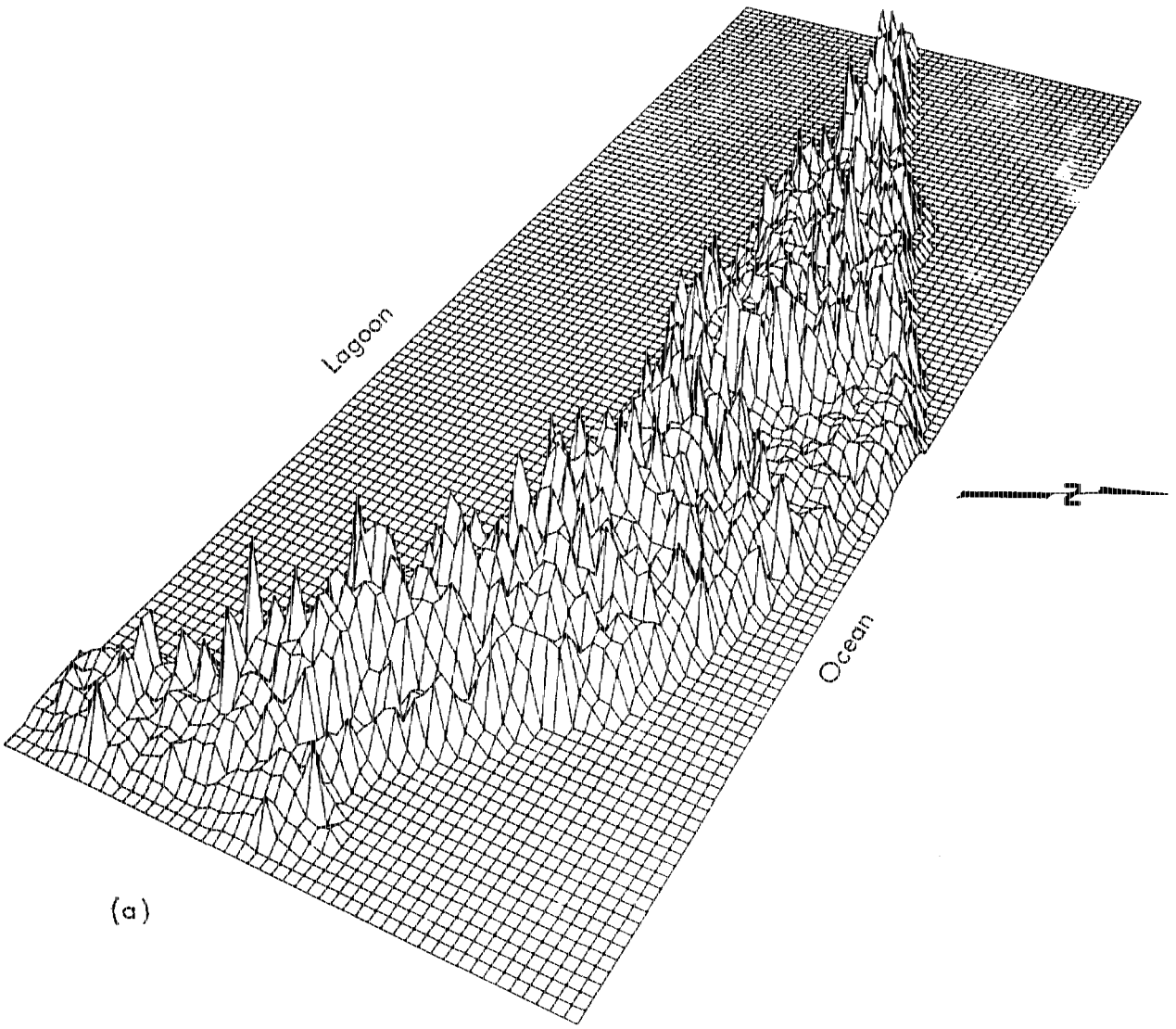

Fig. 6. Three-dimensional graphical representations of the gamma-ray exposure rates measured on Bikini Island as viewed from (a) the ocean side and (b and c) the lagoon side. The vertical coordinate is a measure of the exposure rates. Elevated exposure rates appear as "peaks" while the lesser values show up as relatively low flat areas. Note the lower values along the shores and the higher values within the island's interior. Note also in (a) the low flat area situated on the ocean side near the center of the island.

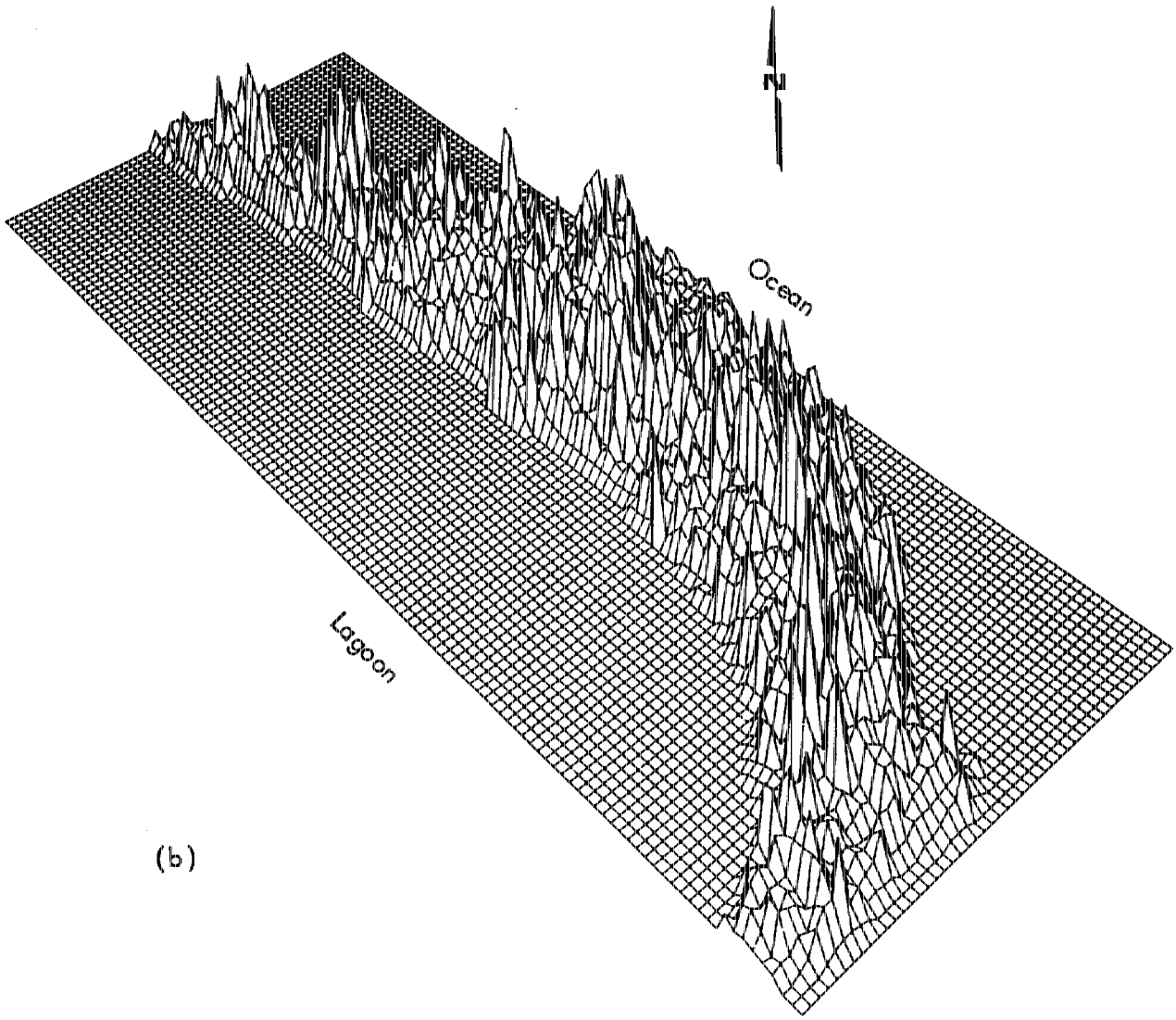

Fig. 6. (continued).

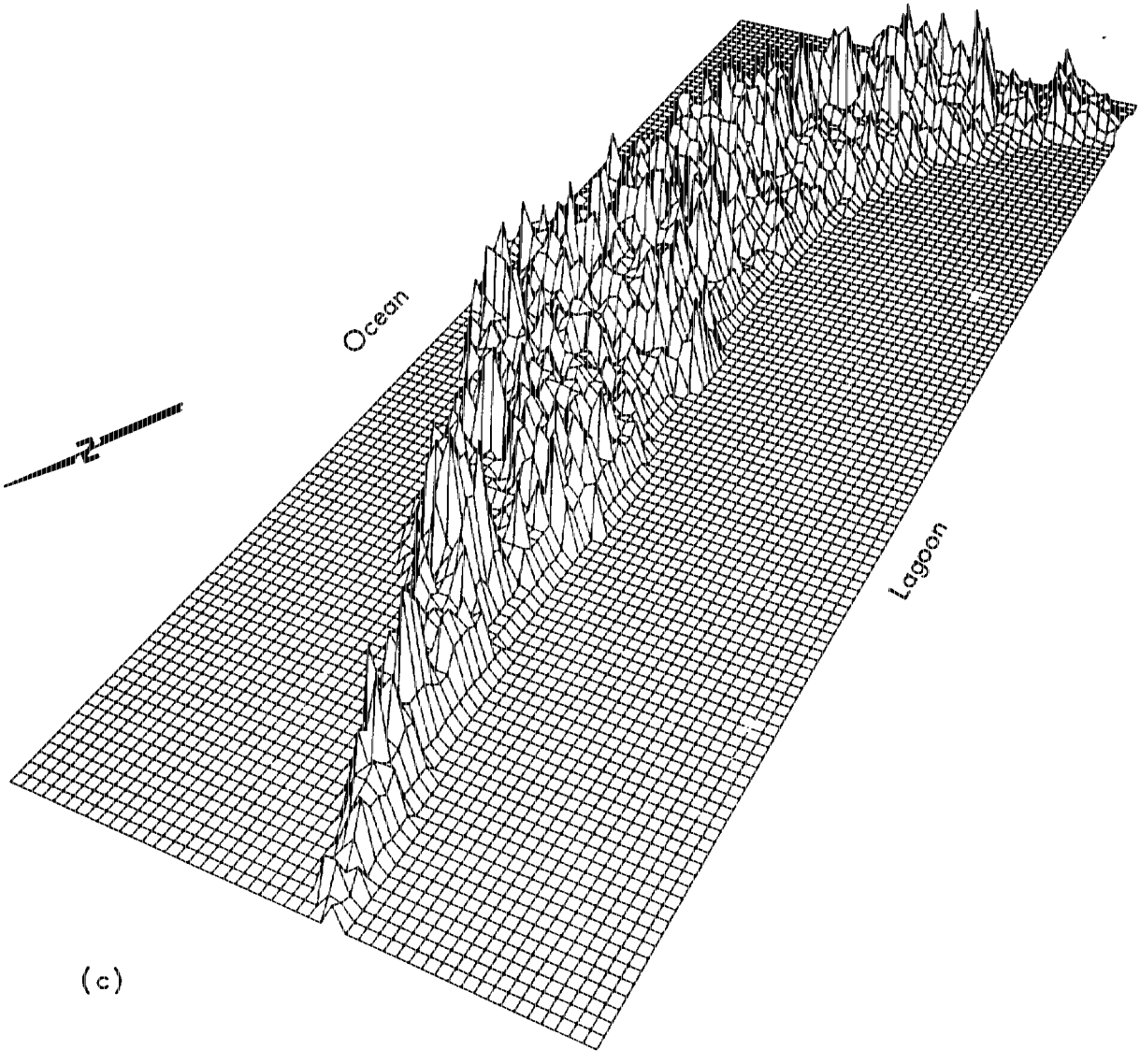

Fig. 6. (continued).

^{155}Eu, and ^{241}Am were expected to contribute at most a few percent to the total exposure rates. This was confirmed by Ge(Li) gamma spectral analyses of several hundred soil samples collected on both islands during the June 1975 survey. The detailed results of the soil survey will be published in a subsequent report. In summary, the soil survey included the random collection of two types of soil samples on each island: surface and profile. Each surface sample consisted of two 15-cm-deep cores. Profile samples were obtained from the sidewall of a trench dug for the purpose. On Bikini Island the median ^{137}Cs and ^{60}Co activities exhibited by the 15-cm-deep core samples were 41 pCi/g and 0.74 pCi/g, respectively; while on Eneu Island, the corresponding values were 2.5 pCi/g and 0.06 pCi/g. As expected, the profile samples showed a wide range of activity distributions as a function of depth on the two islands. Even though generalizations are difficult to make, the activities on Bikini Island usually decreased with depth in the first few centimeters with a relaxation length of about 5 cm (the depth at which the activity is e^{-1}, or 37% of the surface activity). On Eneu Island, the activities were relatively low and uniform throughout the full range of depths sampled. Using these data in conjunction with the data of Beck et al.,[4] we estimated the average ^{137}Cs and ^{60}Co contributions to the total gamma-ray exposure rates over the two islands to be 94% and 6%, respectively. These percentages were assumed to be valid over the remaining islands of the atoll.

External Dose Estimation

In addition to the gamma-ray exposure rates, we need to consider the expected living patterns of the future inhabitants in order to evaluate the external dose problem. Of course, many uncertainties are inherent in the prediction of future living patterns. However, the following cases, shown in Table 1, have been chosen as a reasonable selection of possible conditions that would cover the range of doses that could be received by any sizeable segment of the population. These were based upon our experiences during the Enewetak survey[1] as well as on discussions with personnel from the Trust Territory of the Pacific Islands. Suggestions have also been solicited

Table 1. Assumed living patterns.

Case	Description
1	No use of Bikini Island for the present as a housing or food production area. Use of Eneu Island for housing and food production. Unrestricted use of fish throughout the atoll.
2	Limited use of Bikini Island with residence in houses already constructed. No additional house construction on Bikini Island for the present. Use of coconuts grown on Bikini Island. Other food crops grown on Eneu Island only. Unrestricted use of fish from all parts of the atoll. Use of Bikini Island lens water for agriculture only.
3	Limited use of Bikini Island with the following remedial actions taken: (a) placing 5 cm of clean coral gravel around the existing houses out to a distance of 10 m, and (b) removal of the top 20 cm of soil and replacement with clean soil out to a distance of 10 m around the houses. All foods grown on Bikini Island are acceptable except pandanus and breadfruit. Unrestricted use of fish throughout the atoll. Use of Bikini Island lens water for agriculture only.
4	Limited use of Bikini Island with Phase II houses constructed only along the lagoon road within area 2 of Fig. 7. Remedial actions 3a and 3b are taken. Use of coconuts grown on Bikini Island. No use of pandanus and breadfruit from Bikini Island. Unrestricted use of fish throughout the atoll.
5	Phase II housing construction according to the Preliminary Bikini Atoll Master Plan, but no use of pandanus and breadfruit from Bikini Island. Unrestricted use of fish throughout the atoll. Lens water for agriculture and washing only.
6	Phase II housing constructed according to the Preliminary Bikini Atoll Master Plan. All foods grown on Bikini Island are acceptable. Unrestricted use of fish throughout the atoll. Lens water used for agriculture and washing only.

from the Bikini people. These patterns also allow us to extrapolate other reasonable patterns. Note that the cases also include assumptions on the food production and consumption plans of the returning population. This information is only required for the internal dose assessment via the specific food chains, and hence is not pertinent to the external dose calculations.

The cases are based upon the assumption that the people will reside on either Bikini or Eneu Island in accordance with the Preliminary Bikini Atoll Master Plan.[5] For purposes of this report, the cases are primarily directed toward assessing the external dose associated with various options for housing locations on the two islands. The first case is based on the assumption that the people will live only on Eneu Island. The remaining cases assume residence on Bikini Island at different village sites with various remedial actions being taken to reduce the exposure rates. Thus, cases 2 through 4 assume the residences are situated along the lagoon road on Bikini Island (areas 1 and 2 in Fig. 7), while cases 5 and 6 assume the people will live within the interior portions of the island, shown as area 3 in Fig. 7. As far as the external dose assessment is concerned, cases 5 and 6 are identical. Because the expected living patterns are most likely to differ between the various age groups, age distribution data has been compiled (Table 2). These data were obtained from the 1974 census taken on Kili Island of the 784 persons who claim land rights on Bikini Island.[5] The geographical living patterns, also shown in Table 2, were assumed to be similar to those expected for the returning Enewetak people.[1]

Even though the gamma-ray exposure rates vary widely, it is necessary, for the purpose of the external dose calculations, to derive the most reasonable values of the mean exposure rates for each specific geographical area under consideration (Table 3). The mean exposure rates for specific areas on Bikini Island were obtained by weighting the mean exposure rates within each contour interval (Fig. 4) by the area within the contour. Since the exposure rates on Eneu Island are relatively uniform, the mean exposure rates were chosen by inspection of Fig. 5. Because the survey did not include the other islands of the atoll, we had to rely on data from previous surveys to estimate how much of the total population dose was contributed by

Table 2. Population breakdown by age and geographical living patterns.

	Infants and small children	Children and adolescents	Men	Women
Age bracket (years)	0-4	5-19	20+	20+
Fraction of population (%)	16	41	22	21
Fraction of time spent in respective areas (%):				
Inside home	50	30	30	30
Within 10 m of home	15	10	5	10
Elsewhere in village	5	10	5	10
Beach	5	5	5	5
Interior of island	5	15	20	15
Lagoon	0	10	10	5
Other islands	20	20	25	25

Table 3. Estimated mean exposure rates (μR/h) used for the dose calculations.

Case	Village island	Village	Interior	Beach	Lagoon	Other islands
1	Eneu	4	4	1	3.5	50
2	Bikini	20[a]	38[b]	5	3.5	42
3	Bikini	20[a]	38[b]	5	3.5	42
4	Bikini	30[c]	38[b]	5	3.5	42
5	Bikini	50[d]	37[e]	5	3.5	42
6	Bikini	50[d]	37[e]	5	3.5	42

[a]Includes area 1 in Fig. 7.

[b]Includes areas 3 and 4 in Fig. 7.

[c]Includes area 2 in Fig. 7.

[d]Includes area 3 in Fig. 7.

[e]Includes area 4 less area 3 in Fig. 7.

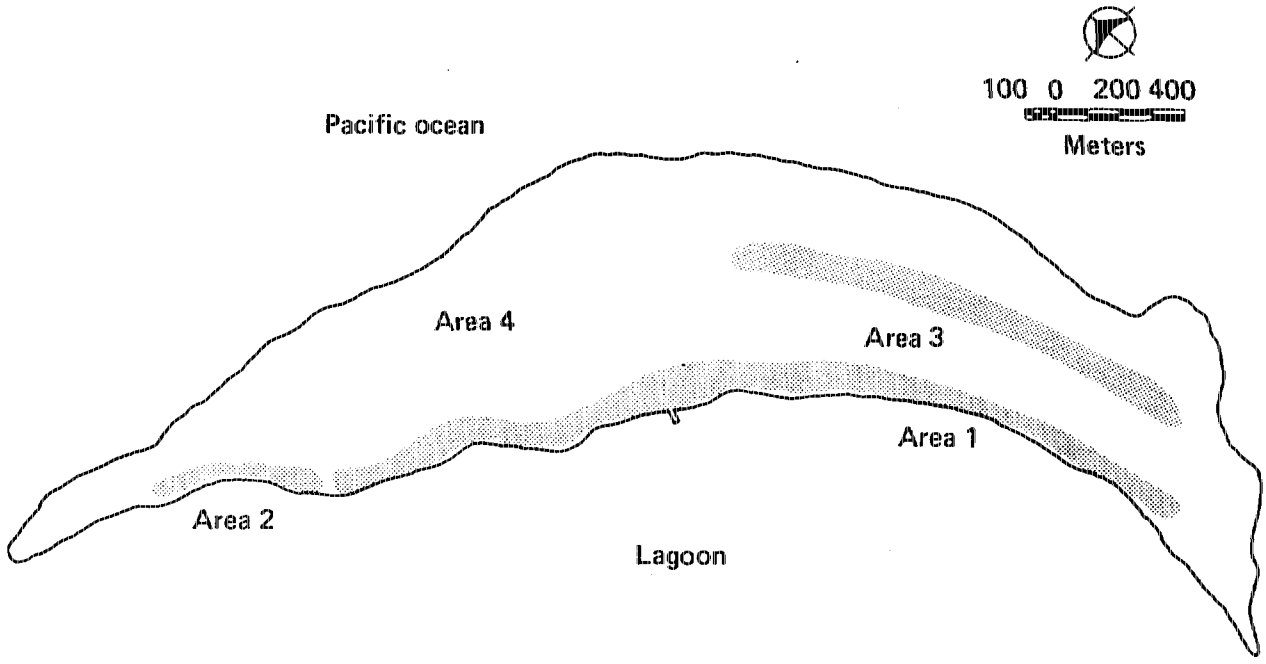

Fig. 7. A map of Bikini Island showing specific areas of interest for the dose calculations. Existing houses are situated within area 1. Areas 2 and 3 are proposed village sites for future housing units. The interior portion of the island is denoted by area 4.

the radioactivity from those islands. Gamma exposure rate data reported by Bennett and Beck,[3] Held,[6] Lynch et al.,[7] Gustafson,[8] Smith and Moore,[9] and Robison et al.[10] were used for this purpose. Their results, in conjunction with a simplified area weighting scheme, yielded the values presented in Table 3. Note that these are rough estimates since the data are scarce and were collected over a span of almost 10 years. The exposure rate over the lagoon was estimated to be 3.3 μR/h due to the cosmic ray contribution and an additional 0.2 μR/h due to naturally occurring radionuclides in the sea water.

Since the islanders spend a considerable fraction of their time in the immediate vicinity of their homes, it may be feasible to take certain remedial actions to reduce the exposure rates in this area. For instance, placing 5 cm of clean coral gravel around the houses out to a distance of 10 m, a common practice in the Marshall Islands, will reduce the exposure rates by a factor of two. Removing and replacing with clean soil the top 20 cm of soil out to a distance of 10 m from the houses will reduce the exposure rates by a factor of eight. In addition, the shielding provided by the houses themselves will reduce the

exposure rates by a factor of two.

On the basis of these data, we calculated the integral first-year and 30-year whole body external gamma-ray doses for each age group for each living pattern presented in Table 1. The results were then combined by "folding in" the present population distribution. The effect of radioactive decay was included in the calculation; however, the additional reduction in exposure rates due to possible weathering, leaching, or agricultural crop production processes was not included.

The results of these calculations and a comparison with appropriate recommended guide values are given in Table 4 for each case under consideration. Of course, these cases are only approximations of the expected living patterns, and the results should be regarded accordingly. The minimum external doses, as we might expect, may be realized by living on Eneu Island. Estimated values, including natural background, are 0.12 rem during the first year and 2.9 rem over 30 years. A significant fraction of these values is due to exposure received while visiting other islands having higher contamination levels. Future inhabitants of the existing houses along the lagoon road on Bikini Island (case 2) may expect to receive first-year and 30-year integral doses of 0.2 and 4.3 rem respectively. Remedial actions (cases 3a and 3b) reduce the 30-year values by a few tenths of a rem. These values would increase somewhat if the Phase II houses (the next group to be built) were constructed within area 2 of Fig. 7 (cases 4a and 4b) because of the higher gamma exposure rates measured in this area. If, on the other hand, the Phase II houses were built within the interior of Bikini Island instead of along the shores (cases 5 and 6) we would expect the external dose levels to increase to about 0.28 rem during the first year and 5.9 rem over 30 years.

Table 5 lists the dose variations between the various age groups for each case. Because the adults are expected to spend a considerable fraction of their time within the interior of Bikini Island as well as on other islands, their dose levels are slightly higher than those of the children. The relative differences, however, are expected to be somewhat overestimated because aging is not considered in the calculations.

These doses may be compared with the appropriate guide values, given in the title of Table 4, which are those set forth by the International

Table 4. Estimated integral whole-body external gamma doses for the first year and for 30 years. Values include contributions due to natural background radiation of about 0.027 rem for a first-year dose and 0.80 rem for a 30-year dose. For comparison, the federal radiation guide (total of external and internal doses) is 0.5 rem per year for individuals and 5 rem for 30 years for a population average. These guides are in excess of natural background.

Case	Description	Estimated doses (rem) First year	30 year
1	Village on Eneu Island	0.12	2.9
2	Residence in houses already constructed along lagoon road on Bikini Island.	0.20	4.3
3	Residence in houses already constructed along lagoon road on Bikini Island with following remedial actions taken:		
	a. Placing 5 cm of gravel around houses	0.18[a]	4.1[a]
	b. Removing and replacing top 20 cm of soil around houses	0.18[a]	4.0[a]
4	Residence in Phase II houses constructed along lagoon road within area 2 of Fig. 7 with following remedial actions taken:		
	a. Placing 5 cm of gravel around houses	0.22[a]	4.8[a]
	b. Removing and replacing top 20 cm of soil around houses	0.20[a]	4.4[a]
5	Residence in Phase II houses constructed within the interior of Bikini Island	0.28	5.9
6	Residence in Phase II houses constructed within the interior of Bikini Island	0.28	5.9

[a]The exposure rates in the immediate vicinity of the houses have been reduced by a factor of two and eight for remedial actions a and b, respectively. However, we have estimated that only 35 to 40% of the Bikinian's time will be spent in the vicinity of his house; therefore, the reduction in total dose is relatively small because the total dose includes the exposure received from the areas where he spends the other 60 to 65% of his time.

Table 5. External 30-year doses for each age group.[a]

Case	Infants and small children	Children and adolescents	Men	Women
1	2.7	2.7	3.1	3.1
2	3.9	4.2	4.5	4.5
3a	3.7	4.0	4.4	4.4
3b	3.5	3.9	4.4	4.2
4a	4.6	4.7	4.9	5.1
4b	4.0	4.3	4.7	4.6
5	6.0	5.8	5.6	6.1
6	6.0	5.8	5.6	6.1

[a]All units are in rem.

Commission on Radiological Protection. While these guidance values for exposures of individuals and of population groups are not a dividing line between safety and danger, any exposures approaching these guides are cause for careful evaluation of the situation, and exposures exceeding the guides would require consideration of remedial measures to reduce exposures and bring them within the guidelines. Inhabitants in the existing houses on Bikini Island are expected to receive external whole-body radiation exposures that are approximately 40% of the annual guide value and about 70% of the 30-year guide value. This leaves little margin for additional radiation doses that may be potentially received by intake of radionuclides via groundwater and various food chains. It is clear from Table 4 that residents in houses built within the interior of Bikini Island will receive 30-year external radiation doses exceeding the guide value.

As mentioned earlier, these external doses may be enhanced by the presence of beta rays emanating from beta emitters such as $^{90}Sr - ^{90}Y$ activities in the soil. It appears

that the beta contribution to the total LiF exposure rates is roughly 25% at three separate sites within the interior of Bikini Island. Even though the beta to gamma ratios at these sites are reasonably constant, it is still difficult to generalize about the variability of this ratio throughout the entire atoll because of differences in the mix of beta to gamma emitters in the soil and the density of the vegetative cover, which can provide shielding for the beta radiation over the surrounding area. Therefore, no attempt has been made to to calculate integrated beta doses in a manner similar to the gamma doses. However, if we assume that the beta to gamma ratio is constant throughout the entire atoll, the additional dose due to the beta contribution will be about 30% of the gamma doses for the skin; about 1% for the eye lenses; and negligible for the gonads. On the basis of these results, we believe that the beta contribution plays a minor part in the total external dose commitment.

Acknowledgments

The field portion of the June 1975 radiological survey of Bikini and Eneu Islands of Bikini Atoll was accomplished by a very intense and thorough effort by 21 people representing six different organizations. The number of samples collected and the amount of information obtained during the ten-day survey is a direct result of the cooperation and diligent effort of the following individuals:

Wayne Bliss	Environmental Protection Agency, Las Vegas, Nevada
Bruce Clegg	Lawrence Livermore Laboratory
Dave Coles	Lawrence Livermore Laboratory
Tom Crites	Lawrence Livermore Laboratory
Rod Eagle	Lawrence Livermore Laboratory
Harley Erwicker	Trust Territory of the Pacific Islands
Nat Greenhouse	Brookhaven National Laboratory
Paul Gudiksen	Lawrence Livermore Laboratory
Gale Holladay	Lawrence Livermore Laboratory
Bob Keller	Nevada Operations Office (ERDA)
Dennis McBreen	Trust Territory of the Pacific Islands
Tommy McCraw	Division of Operational Safety (ERDA)
Ben Mendoza	Lawrence Livermore Laboratory
Vic Nelson	University of Washington
Vic Noshkin	Lawrence Livermore Laboratory
Frank Reed	Environmental Protection Agency, Las Vegas, Nevada
Jim Schweiger	Lawrence Livermore Laboratory
Robert Spies	Lawrence Livermore Laboratory
John Stewart	Nevada Operations Office (ERDA)
Marshall Stuart	Lawrence Livermore Laboratory

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Mike Allen	Harris Levy
Ruth Anderson	Austin Prindle
Keith Hamby	Robert Wikkerink
Jesse Meadows	

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William L. Robison
Technical Director
Bikini Survey June 1975

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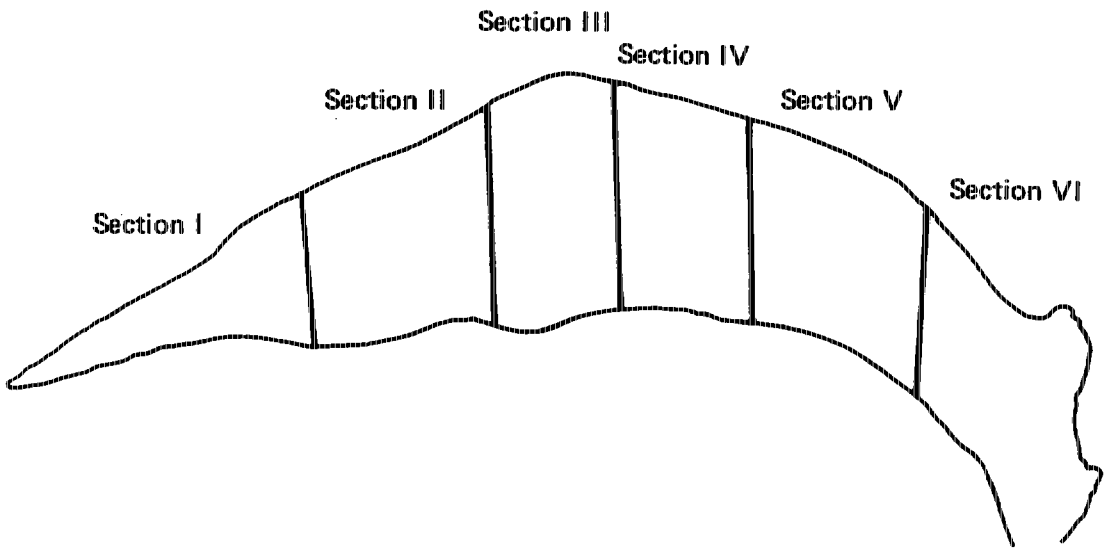
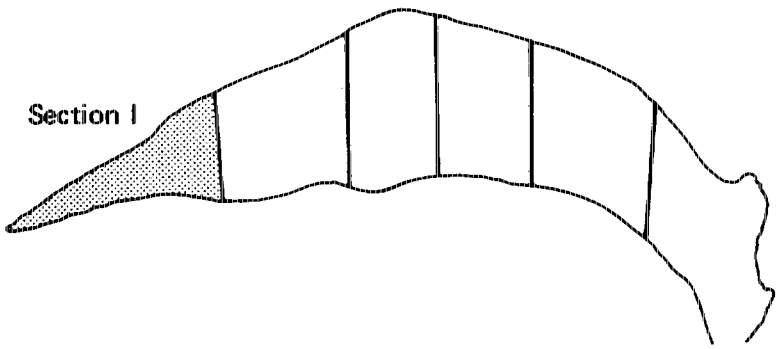
MSG/gw/mp/wl

Appendix
Gamma-Ray Exposure Rate Measurements (μR/h) on Bikini Island





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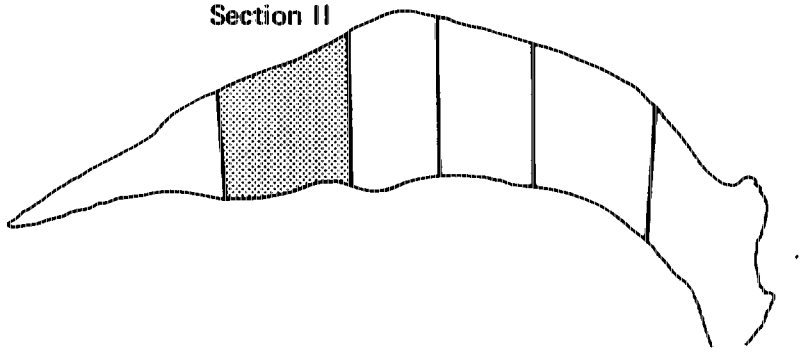

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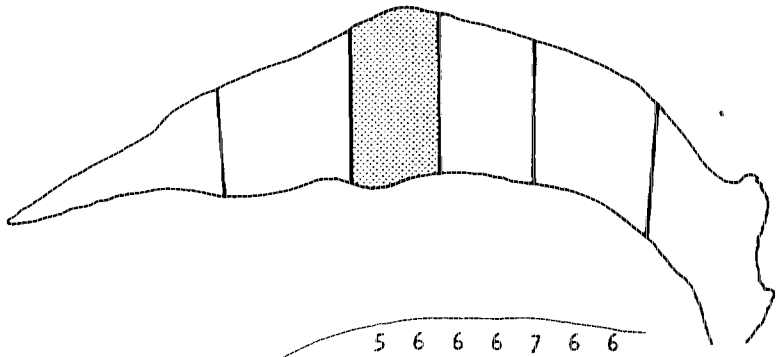

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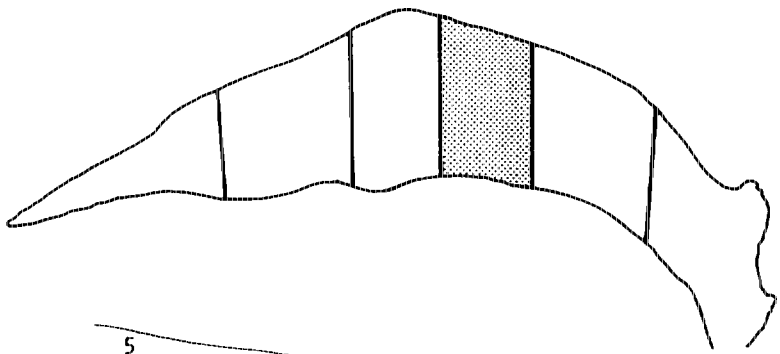

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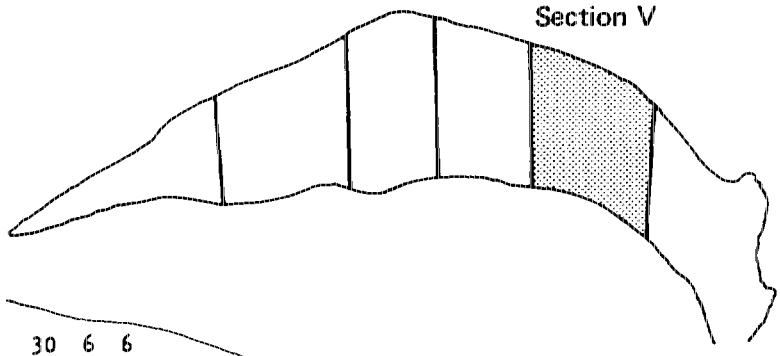

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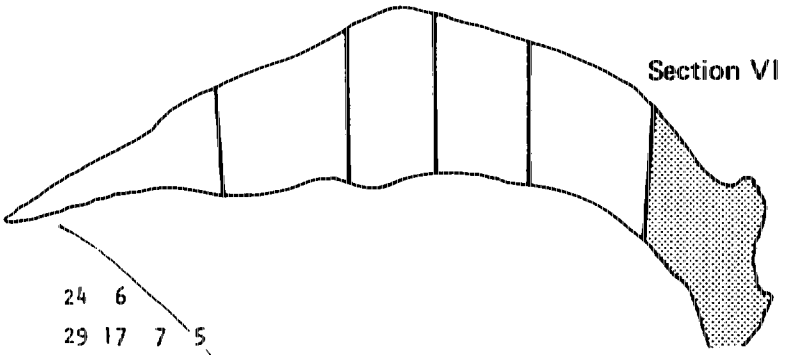

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